Indian J. Phys. **74B** (5), 335–336 (2000)

RAPID COMMUNICATION

I J P B
an international journal

Calculation of singly differential cross section for electron-impact ionization of helium at 100 eV

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[Communicated through Prof S C Mukherjee]

Received 5 July 2000, accepted 8 August 2000

Abstract We report singly differential cross section for electron impact ionization of helium at the incident energy of 100 eV. The calculation is based on the Glauber approximation. At low energies of ejection, the present results are in good agreement with experiment.

Keywords Glauber approximation, ionization cross section.

PACS Nos. 34.80 Dp, 34.50 Fa

In a previous communication [1], we applied the Glauber approximation (GA) [2,3] to obtain doubly differential cross section (DDCS) for the primary electrons for the He (e, 2e) He$^+$ reaction process at incident energies of 100, 300 and 500 eV. The calculations were done for the asymmetric geometry, *i.e.* one of the outgoing electrons is fast while the other is slow. It has been pointed out that the DDCS predicted by the GA are in reasonably good agreement with experiment and with the distorted wave Born calculation of McCarthy and Zhang [4].

In view of the success, we extend the GA to generate singly differential cross section (SDCS) for electron-impact ionization of helium at the incident energy of 100 eV. We have chosen this energy because both the theoretical results of Bray and Fursa [5] and the experimental data of Roder *et al* [6] are available at that energy. The energy range of the secondary electrons is from 1 eV to 15 eV.

The theory used in this communication is described in detail elsewhere [3,7,1]. Here we give only a short overview. In the GA, the amplitude for ionization of He by electron impact is given by (atomic units are used throughout, unless otherwise indicated)

$$F(\mathbf{q},\mathbf{k}_2) = ik/2\pi \int d\mathbf{b}\,d\mathbf{r}_1\,d\mathbf{r}_2\,\phi_f^*(\mathbf{r}_1,\mathbf{r}_2)\Gamma(\mathbf{b},\mathbf{r}_1,\mathbf{r}_2)\,\phi_i(\mathbf{r}_1,\mathbf{r}_2)\exp(i\mathbf{q}.\mathbf{b}). \tag{1}$$

where $\Gamma(\mathbf{b};\mathbf{r}_1,\mathbf{r}_2) = 1 - \left[|\mathbf{b}-\mathbf{s}_1|\right]^{2i\eta}\left[|\mathbf{b}-\mathbf{s}_2|\right]^{2i\eta}$

$\mathbf{q} = \mathbf{k} - \mathbf{k}_1$ and $\eta = 1/k$. Here $\mathbf{k}$, $\mathbf{k}_1$ and $\mathbf{k}_2$ are the momenta of the incident, scattered (primary), and ejected (secondary) electrons, respectively. $\mathbf{b}$, $\mathbf{s}_1$ and $\mathbf{s}_2$ are the respective projections of the position vectors of the incident particle and the two bound electrons onto the plane perpendicular to the direction of the Glauber path integration.

In eq (1), $\mathbf{q}$, $\mathbf{b}$, $\mathbf{s}_1$ and $\mathbf{s}_2$ are all coplanar. $\phi_i(\mathbf{r}_1, \mathbf{r}_2)$ and $\phi_f(\mathbf{r}_1, \mathbf{r}_2)$ represent the wave functions of the initial and final states of the target repectively. For the initial state of He, we have chosen the analytical fit to the Hartree Fock wave function given by Byron and Joachain [8] :

$$\phi_i(\mathbf{r}_1, \mathbf{r}_2) = U(\mathbf{r}_1)U(\mathbf{r}_2), \tag{2}$$

where $U(\mathbf{r}) = (4\pi)^{-1/2}(Ae^{-\alpha r} + Be^{-\beta r})$,

$A = 2.06505$, $B = 2.08144$, $\alpha = 1.41$, $\beta = 2.61$.

For the final state wave function, we have used a symmetrized product of the He$^+$ ground-state wave function for the bound electron times a coulomb wave ϕ_{k_2} orthogonalized to the ground state orbital

$$\phi_f(\mathbf{r}_1,\mathbf{r}_2) = 2^{-1/2}\left[\phi_{k_2}(\mathbf{r}_1)\nu(\mathbf{r}_2) + \nu(\mathbf{r}_1)\phi_{k_2}(\mathbf{r}_2)\right], \tag{3}$$

where $\nu(\mathbf{r}) = (\lambda')^{3/2}\pi^{-1/2}e^{-\lambda' r}$,

$$\phi_{k_2}(\mathbf{r}) = \chi_{k_2}(\mathbf{r}) - \langle U(\mathbf{r}')|\chi_{k_2}(\mathbf{r}')\rangle U(\mathbf{r}),$$

$$\chi_{k_2}(\mathbf{r}) = (2\pi)^{-3/2}\exp\left(\frac{1}{2}\gamma\pi\right)\Gamma(1+i\gamma)\exp(i\mathbf{k}_2.\mathbf{r})\,{}_1F_1(-i\gamma,1,-i\mathbf{k}_2.\mathbf{r}),$$

$\gamma = 1/k_2$, $\lambda' = 2$.

The singly differential cross section is given by

$$\frac{d\sigma}{dE_2} = \frac{k_1 k_2}{:} \int d\hat{k}_1 d\hat{k}_2 |F(q, k_2)|^2 \quad (4)$$

The present calculation is performed using the technique of Roy *et al* [7] that reduces the eight dimensional Glauber amplitude for the He (e, 2e) He^+ process to a 3-dimensional integral. Figure 1 exhibits a graphical comparison of the GA

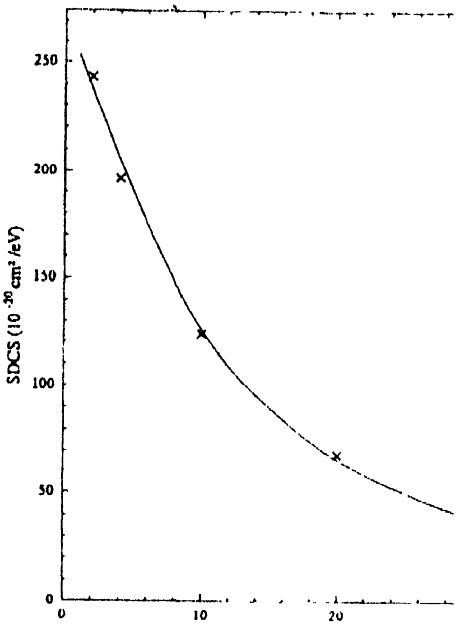

Figure 1. Singly differential cross section in units of 10^{-20} cm^2/eV for He (e, 2e) He^+ process at the incident energy of 100 eV. The full curve represents the present GA calculation whereas the crosses denote the experimental data of Roder *et al* [6].

with the corresponding experimental data of Roder *et al* [6] who integrated the DDCS over the angles of the observed electron to obtain the SDCS. The measured data of Roder *et al* were however relative. They were made absolute, using the convergent close coupling (CCC) calculations of Bray and Fursa [5] at 100 eV. Figure 1 shows that the cross sections predicted by the present method are in very good agreement with experiment at low energies of ejection. They also agree closely with the corresponding CCC cross sections which almost coincide with the experimental data and are not shown in the figure. A slight departure from experiment is, however, noted in the case of near symmetic geometry. This discrepancy may be assigned to the omission of electron-electron exchange and of the final state electron-electron correlation in the present formalism.

In summary, we have calculated singly differential cross sections for electron-impact ionization of helium at the incident energy of 100 eV using the Glauber approximation. At low energies of ejection, the cross sections predicted by the present method are in good agreement with the convergent close coupling calculation of Bray and Fursa and experiment.

Further calculation at lower incident energies is on the way.

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